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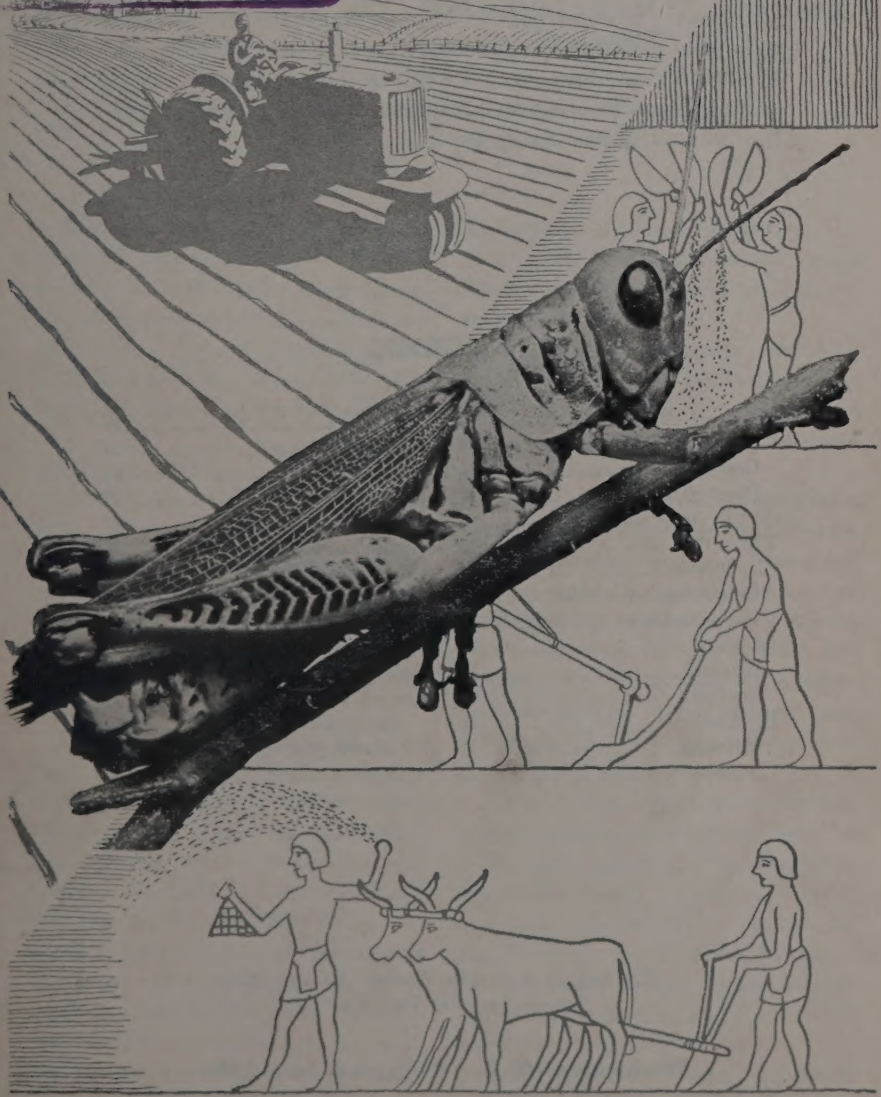
GRASSHOPPERS

A New Look at an Ancient Enemy



FARMERS' BULLETIN No. 2064
UNITED STATES DEPARTMENT OF AGRICULTURE

1954

This bulletin on grasshoppers is intended to help farmers, county agricultural agents, and entomologists. It presents the more important facts about grasshoppers in everyday language. It describes the damage that these insects do; it tells what different species look like, how they develop, and where and how they live; it explains how outbreaks occur. With this information as background, the final section tells how to control grasshoppers.

CONTENTS

Nature of damage	4	The adults	19
Crops	4	Reproduction	19
Grass	5	Flights	22
Other damage	7	Cannibals	25
On the credit side	8	Maneaters	25
Where they live	8	Natural enemies	26
Classification	9	Effect of weather	28
Crop-damaging species	10	Temperature	28
Range-damaging species	13	Rainfall	29
Structure	14	Weather combinations	30
External	14	Outbreaks	30
Internal	17	Control measures	31
Development	18	Sprays and dusts	32
Hatching	18	Cultural practices	37
Molting	19	Other measures	39

This bulletin supersedes Farmers' Bulletin 1828, Grasshoppers and Their Control

Washington, D. C. • Issued June 1954

GRASSHOPPERS

A New Look at an Ancient Enemy

By J. R. PARKER, entomologist, Entomology Research Branch,
Agricultural Research Service

Man has written about grasshoppers ever since he began to write. We find accounts of their ravages in the literature of the ancient Egyptians, Hebrews, and Greeks. They are mentioned many times in the Bible. Joel 2: 3 gives us this vivid description of what they do:

> * * * the land is as the garden of Eden before them, and behind them a desolate wilderness; yea, and nothing shall escape them.

The ancient writers called them locusts. In Latin the equivalent of the word "locust" means "a burned place." The aptness of the term is easily appreciated by anyone who has seen an area devastated by grasshoppers.

Their devastation is recorded in the early history of our own country. In 1740 grasshoppers attacked the scanty crops of the Massachusetts Colony. The colonists armed themselves with bundles of brush, and drove millions into the ocean. In 1805 Lewis and Clark found them in great numbers in Montana. In 1818 they destroyed the crops of settlers in Minnesota. In 1877 the stream of covered wagons then rolling westward was temporarily halted by swarms of grasshoppers that left many of the homeseekers without grass for their animals and without food for themselves.

Layers of grasshoppers embedded deep in glaciers of the Rocky Mountains prove that they flew over these mountains centuries before the white man came to America.

Grasshoppers still cause agricultural catastrophes. Every year they destroy crops somewhere in this country, and during outbreak periods they cause losses that run into millions of dollars. Businessmen, as well as farmers and ranchers, lose financially when grasshoppers destroy crops, pastures, and range forage. Anything that hurts agriculture hurts business.

You can protect your crops, pastures, and rangelands from grasshoppers by killing them whenever they increase to unusual numbers. Control is easier and more certain than it used to be. Grasshoppers can be killed by astonishingly small dosages of new insecticides, and methods of applying insecticides have been improved.

You can prevent damage by grass-

hoppers that originate on your own land. But this is only a part of the task. Your land may be overrun by grasshoppers originating elsewhere. Complete protection can be obtained only by united efforts of individuals, communities, States, and Federal agencies.

NATURE OF DAMAGE

CROPS

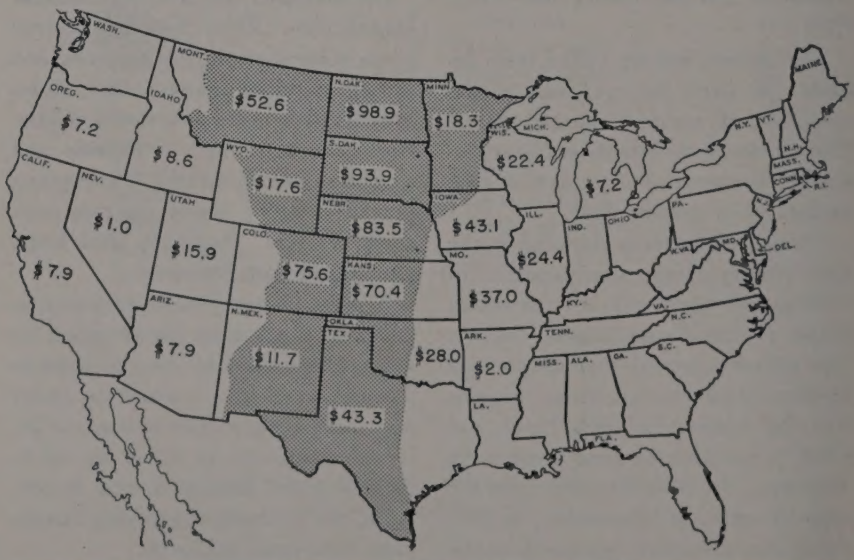
In the United States the areas that are favorable to grasshopper development take in areas where most of our wheat, barley, and flax are grown. They also take in enormous acreages of alfalfa, corn, oats, and rye. All these crops are susceptible to grasshopper attack and are damaged to some extent every year. When populations are low, damage is slight. When severe outbreaks occur, and control measures are not used, crops are destroyed.

Estimates made by grasshopper-control leaders in 23 Western States give us an idea of the economic losses due to grasshopper damage to crops. During the 5-year outbreak period 1934 to 1938, average yearly losses were nearly $63,000,000, with a total of $315,753,000. During the 25-year period 1925 to 1949, which included both outbreak and nonoutbreak years, average yearly losses were about $31,000,000, with a total of $779,516,000. Distribution of losses by States is shown on the accompanying map.

In the other States there is some damage to crops by grasshoppers every year, but estimates of the losses are not available.

Some kinds of grasshoppers will eat almost anything; others feed on only a few plants and starve to death if they cannot find them.

The kinds that injure crops are gen-



Grasshopper damage to crops in millions of dollars, 1925 to 1949, by State. Heaviest losses occur where average annual rainfall is 10 to 30 inches (shaded region on map).

Grasshopper damage to tall corn. In bad outbreaks stalks may be eaten to the ground.

eral feeders. During severe outbreaks they devour entire crops of small grains, corn, soybeans, cotton, alfalfa, clover, and grasses. After crops are destroyed they even attack trees.

Grasshoppers destroy the commercially valuable portions of some plants by feeding on other portions. By feeding on the stems of grain, flax, and cotton plants, they sever grain heads and bolls, which fall to the ground. By feeding on corn silks, they prevent pollination and the filling of the ears. Where grasshoppers' feeding produces "strategic destruction" of this kind, a small number may inflict heavy damage before the farmer notices what they are doing.

An attack on the blooms of alfalfa and clover, which are preferred to the foliage, means heavy losses to beekeepers and seedgrowers.

Grasshoppers hatch in the spring about the time crops are planted, and adults persist until crops are harvested. Young hoppers are as voracious as older, larger ones. Crops are thus open to attack throughout the growing season.

GRASS

Grasshoppers do heavy damage to range and pasture lands. Few estimates of the financial losses are available. The Forest Service reported that in 1934 grasshopper injury to range vegetation in national forests in Colorado, Montana, Nebraska, North Dakota, South Dakota, and Wyoming amounted to $2,455,000. Damage to privately

After stripping the leaves from this boxelder tree, grasshoppers ate some of the bark.

owned ranges in Wyoming in 1936 was estimated at $1,480,000 by the State entomologist. These figures cover only the normal value of the forage. They do not include indirect losses, such as those incurred by forced sale of livestock.

Most range grasshoppers are not such general feeders as crop grasshoppers. Some species eat only grass, some feed on plants other than grass, and some prefer shrubs. Since as many as 20 species may be found living together, nearly all range vegetation is subject to attack, despite the specialized feeding.

Even in a light infestation on a range, with an average of 6 or 7 grasshoppers to the square yard, those on 10 acres consume grass at about the same rate as a cow; if the grass is sparse, the amount thus destroyed may reduce the supply to the point where cattle can no longer subsist on it. During outbreaks, when there may be 30 to 60 to the square yard, all the grass may be destroyed.

The economic damage done by a given number of grasshoppers on a given area of range varies with such things as changes in temperature and rainfall. During cool weather and abundant rainfall, grass is likely to be plentiful, and the amount consumed by the hoppers is not economically significant. In hot, dry weather, however, grass is likely to be scarce, and the amount consumed is a serious matter. Also some grasshoppers eat more in hot weather than in cool weather.

Like grasshoppers on crops, those on

a range do damage that goes beyond actual feeding damage. They cut stems and blades and eat only part of them; they prevent reseeding; they eat the grass closer than livestock, and when extremely abundant they sometimes injure the crowns of the plants to such an extent that growth is retarded for several years thereafter. Overgrazing by grasshoppers, particularly during drought years, exposes the soil to erosion by wind and water. Some of our worst soil blowing has followed grasshopper outbreaks.

OTHER DAMAGE

Our main charge against grasshoppers is that they destroy our crops and grass. But when they are extremely abundant they cause trouble in a number of other ways.

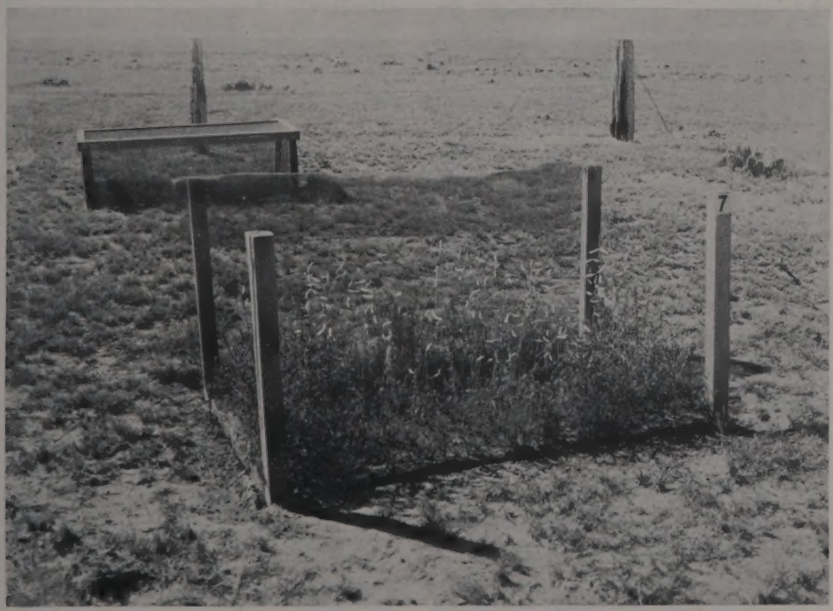
They cut binder twine. They eat holes in clothes hanging on the line. They get inside homes, where they damage clothing and curtains. In army camps they eat holes in tents and parachutes.

They pollute water by getting into springs, wells, cisterns, and reservoirs.

When grasshoppers are grabbed or slapped, the pressure forces black digestive juice ("grasshopper tobacco juice") from their mouths. The juice forms a stain that is hard to remove from clothing.

Grasshoppers that collide with automobiles are an annoyance and a hazard to motorists. They smear the bodies of cars and, unless kept out with screens, plug radiators. They increase driving hazards by smashing into windshields and flying into drivers' faces.

Trains have been delayed because they could not run at regular speed on tracks made slippery by crushed grasshoppers.



Grasshopper damage to grama grass on rangeland. Note short grass, lack of seedheads, and bare spots. Contrast with grass that was protected from grasshoppers by screens.

ON THE CREDIT SIDE

Much has been said against grasshoppers. It seems only fair to mention a few things in their favor.

They make good fish bait. Thousands of fishermen use them for that purpose every summer. No other live bait, except angleworms, is more widely used in trout fishing. If you can't catch them alive, you can buy dried or pickled ones from your sporting goods store.

When they are plentiful, they are eaten in great numbers by game birds and unconfined poultry, and make good food for them.

People in many lands have used grasshoppers as food. They have done so for centuries and still do. That grasshoppers were once considered "fit for a king" can be inferred from a carving made 6 or 7 centuries before the birth of Christ; it depicts servants bringing locusts (grasshoppers) to the table of an Assyrian king.

They were eaten by the Indians in North America and by primitive tribes in many other parts of the world. They are eaten today by some civilized peoples. In Mexico roasted grasshoppers are sold on street corners. In Japan grasshoppers are sold as food; they are considered a delicacy when roasted or steamed. The Philippine Government has published a pamphlet that describes 33 ways of cooking them.

In the United States the idea of grasshoppers as food for human consumption has never caught the public's fancy. However, efforts to popularize the idea have been made.

In 1875, when the Rocky Mountain grasshopper was extremely abundant, C. V. Riley, then Missouri State entomologist, and later chief of the United States Entomological Commission, did his best to get the public interested in grasshoppers as food. He was able to cite his own experience in support of his contention that they are good to eat. He said: [1]

> Whenever the occasion presented, I partook of locusts [i. e., grasshoppers] prepared in different ways, and one day ate of no other kind of food, * * *. Commencing the experiments with some misgivings, and fully expecting to have to overcome disagreeable flavor, I was soon most agreeably surprised to find that the insects were quite palatable in whatever way prepared. * * * A broth, made by boiling the unfledged *Calopteni* [i. e., Rocky Mountain grasshoppers] for 2 hours in the proper quantity of water, and seasoned with nothing but pepper and salt, is quite palatable and scarcely to be distinguished from beef broth, though it has a slight flavor peculiar to it and not easy to be described. * * * Fried or roasted in nothing but their own oil, with the addition of a little salt, they are by no means unpleasant eating and have quite a nutty flavor. In fact it is a flavor, like most peculiar and not unpleasant flavors, that one can soon learn to get fond of. * * *

WHERE THEY LIVE

Grasshoppers are widely spread over the United States. They occur in every State.

They thrive in moderately dry weather. They do not thrive in extremely dry weather, which reduces their food supply, or in weather marked by prolonged rains, cloudiness, and high humidity, because under these con-

[1] Quoted in the First Annual Report of the United States Entomological Commission (1878), p. 440.

ditions they succumb to bacterial and fungus diseases.

Judging from the frequency, intensity, and extent of outbreaks and the numbers present between outbreaks, the most favorable climate for grasshoppers in the United States is that of the subhumid and semiarid region in which the average annual rainfall is between 10 and 30 inches. The eastern boundary of this region normally has 30 inches of rain. It extends from Canada through eastern Minnesota, western Iowa, eastern Nebraska, eastern Kansas, central Oklahoma, and central Texas to the Gulf of Mexico. The western boundary has 10 to 15 inches of rain. It follows the foothills along the eastern slope of the Continental Divide from Canada to Mexico. (See map, p. 4.)

Grasshopper increase in the eastern half of the United States appears to be prevented primarily by the heavier rainfall in that region. From the eastern boundary of the zone of greatest abundance to the Atlantic coast, the average annual rainfall increases from 30 inches to 45 inches.

The 30-inch rainfall line varies from year to year, and during drought periods moves eastward into Wisconsin, Michigan, Illinois, Missouri, and Arkansas. When drought continues for several years, grasshoppers increase and damage crops seriously in these States.

Farther east, extreme outbreaks are rare, but localized outbreaks sometimes occur in the New England States and in New York, Virginia, Florida, and Mississippi. Every year grasshoppers cause some damage in most Eastern States.

West of the Continental Divide, local outbreaks occur in subhumid and semiarid sections of Arizona, California, Idaho, Nevada, Oregon, Utah, and Washington.

CLASSIFICATION

Grasshoppers are among our most common insects. Most of us learned to know them when we were children—perhaps when we were catching them for fish bait. We know a grasshopper when we see one. To identify the different kinds (species) is much more difficult, and not many entomologists can identify the less common kinds readily.

Insects are separated into groups called orders, families, subfamilies, genera, and species. Entomologists give Latin names to these groups. For scientific purposes Latin names are better than common names because they are precise. Common names are used loosely, and provide no certain way of distinguishing between groups that are closely related. Also an insect may be known by more than one common name.

Grasshoppers belong to the family Acrididae of the order Orthoptera. (Other members of the Orthoptera are cockroaches, praying mantids, katydids, walkingsticks, and crickets.) In most of the States that comprise the region in which severe outbreaks occur, there are more than 100 species. About 600 species have been identified in the United States and Canada. Some of the more abundant species have common names, but most of the others are known only by the Latin names that were given to them by entomologists when they were first recognized as distinct species.

288990°—54——2

Red-legged grasshopper: Adult male. 3× natural size.

Clear-winged grasshopper: Adult male. 2× natural size.

The terms "grasshopper" and "locust" offer a good example of how common names are confused. In most foreign countries "locusts" is used to designate grasshoppers that march in bands (before they get their wings) and fly in swarms (after they become adults). Thus individuals of the same species may be "grasshoppers" when they are scarce and solitary, and "locusts" when abundant and gregarious. The exact point at which the shift in terminology becomes appropriate is difficult to determine. Even entomologists are often in doubt as to where to draw the line. In the United States the terminology is further confused by the fact that the periodical cicada and its relatives, which are not like grasshoppers in either appearance or habits, are widely known as locusts. Since everyone in this country understands the term "grasshopper" as it is commonly used, it seems preferable to use the single term instead of changing to "locust" when grasshoppers start traveling in bands and swarms. When this happens, they can be called migratory grasshoppers.

Only a few species have become abundant enough to injure crops seriously. A greater number attack range vegetation. The remaining species are of little economic importance.

CROP-DAMAGING SPECIES

At least 90 percent of all grasshopper damage to crops in the United States is caused by five species. The common names of these species, together with the scientific names, are as follows:

Migratory grasshopper
Melanoplus mexicanus mexicanus

Differential grasshopper
Melanoplus differentialis

Two-striped grasshopper
Melanoplus bivittatus

Red-legged grasshopper
Melanoplus femur-rubrum

Clear-winged grasshopper
Camnula pellucida

Another species that should be mentioned is the American grasshopper (*Schistocerca americana*). It sometimes does considerable damage to field crops and orchard fruits in Alabama, Georgia, Florida, Louisiana, and Mississippi.

Appearance

The migratory grasshopper is reddish brown, with an irregular black patch on the neck, or collar, and is about 1 inch long.

The differential grasshopper is usually yellow, with contrasting black markings and clear, glossy outer wings. (Some individuals are predominantly black instead of yellow.) The hind thighs bear distinctive black bars arranged like chevrons. The adult is about 1½ inches long.

The two-striped grasshopper gets its name from the two conspicuous light-colored stripes that run the length of its back from the head to the wingtips. The general body color is greenish yellow. There are contrasting black or brown markings. The wings are colorless. It is about 1¼ inches long.

The red-legged grasshopper is reddish brown above and sulfur yellow beneath. Its hind legs are usually tinged with bright red, and its wings are colorless. It is about ¾ inch long.

The clear-winged grasshopper is yellow to dark brown. The underwings are clear, but the outer wings are blotched with large, dark-brown spots. It is about 1 inch long.

The American grasshopper is about 2½ inches long, and is one of our largest species. Some call it a "bird grasshopper," because it has a wingspread of 4 inches, takes off like a bird when disturbed, and often lights in trees. It is handsomely colored in tan, white, and pink.

Grasshoppers reduce corn yield by cutting silks before pollination is completed. The damage prevents the ears from filling.

Distribution

The migratory, two-striped, and red-legged grasshoppers are found throughout the United States. The differential grasshopper is only occasionally found in large numbers north of the southern

borders of Minnesota, North Dakota, and Montana. The clear-winged grasshopper occurs most abundantly in the States bordering Canada from Michigan to Washington, and in the foothills and mountain valleys of South Dakota, Wyoming, Colorado, Idaho, Utah, Nevada, Oregon, and California.

Of the five species, the migratory grasshopper is the most widely distributed and most destructive.

Favored Habitats

The migratory grasshopper normally selects well-drained, light soil and sparse vegetation in cropped fields or idle land. The differential, two-striped, and red-legged grasshoppers prefer moist, heavy soil, and rank, growing vegetation. The clear-winged grasshopper adapts itself to many conditions, but is most likely to be found in mountain meadows, grassy openings in timbered land, cutover land, and well-sodded, closely grazed pastures on the open plains. Under outbreak conditions all five species spread far from favored habitats and feed on a wide variety of crops and native vegetation.

Migratory Habits

The migratory grasshopper migrates farther and more often than any of our other present-day crop or range grasshoppers. The adults are strong fliers. They sometimes gather in swarms, which migrate hundreds of miles. They destroy crops and range plants wherever they pause.

In 1938 swarms of the migratory grasshopper originating in North Dakota and South Dakota invaded Montana, Minnesota, Nebraska, and two Canadian provinces—Manitoba and Saskatchewan. Carried by winds from the southeast, the swarms entering Montana traveled a third of the way across the State. Their progeny continued northwestward in 1939 and reached Alberta, Canada, in 1940. Counting crop damage and money spent for control, losses directly traceable to the 1938 swarms and to their 1939 and 1940 progeny exceeded $62 million.

The only grasshopper in the United States that has ever shown greater migratory power is the Rocky Mountain grasshopper, which for years had the scientific name *Melanoplus spretus*. It has disappeared from the places where it was once so abundant, and the migratory grasshopper now thrives in those places. From 1874 to 1877 the depredations of the Rocky Mountain grasshopper were considered a national calamity. Great swarms originated in the plains east of the Rocky Mountains in Montana, Wyoming, and Colorado, and migrated to the Mississippi Valley and to Texas. Farmers were left destitute. Eastern relief agencies sent food and clothing to them.

Except for its brighter colors, longer wings, and greater flying ability, the Rocky Mountain grasshopper closely resembled the migratory grasshopper. Many entomologists believe that it was an extreme migratory "phase" of the migratory grasshopper and not a different species.

Among the five species of common crop grasshoppers, the clear-winged grasshopper ranks next to the migratory grasshopper in travel propensities. The adults do considerable flying, but swarms do not appear so frequently or travel so far as swarms of the migratory grasshopper.

Grasshoppers on the march sometimes form bands several miles long and 1/8 mile wide.

The two-striped, differential, and red-legged grasshoppers are comparatively weak fliers, and usually stay close to where they hatch. When they are numerous, and the weather is hot and dry, all three species have been known to develop longer wings, slimmer bodies, and considerable flying ability.

Persons who plan control of grasshoppers must consider their migratory habits. Grasshoppers in Eastern States seldom migrate. Farmers in those States usually have only their own grasshoppers to contend with in control operations. Western farmers may do a good job of controlling their own grasshoppers, yet lose their crops to those that come from other farms, counties, or States.

RANGE-DAMAGING SPECIES

In contrast to the few species of grasshoppers that attack crops, more than 100 species feed on range vegetation. A dozen can generally be found living together on every section of grazing land. Few of them have common names. The scientific names of only a few will be mentioned here.

The migratory grasshopper, already discussed as a species that attacks crops, is also found on the range, and is frequently the dominant species.

The long-winged plains grasshopper (*Dissosteira longipennis*) and *Melanoplus rugglesi* (no common name) are migratory and highly destructive during outbreaks. The adults fly in

An example of rangeland exposed to erosion by severe damage to grass. The hillsides are practically barren following a grasshopper outbreak, and the soil is washing away.

swarms, and gang up to lay their eggs in well-defined beds. Outbreaks of the long-winged plains grasshopper have occurred in Colorado, New Mexico, Oklahoma, and Texas. Outbreaks of *rugglesi* have been limited to Nevada, southern Oregon, and northeastern California. These species are of little economic importance between outbreaks.

The long-winged plains grasshopper measures 2 inches from head to wingtips, and is one of our larger species. The general body color is light tan. The basal part of the underwings is solid dark brown or black; the outer wings are flecked with dark-brown markings.

Melanoplus rugglesi resembles the migratory grasshopper in general appearance and size. A distinguishing characteristic is the dark-orange color inside the hind thigh of *rugglesi*.

Some of the common western-range grasshoppers that are found in considerable numbers every year are *Aulocara elliotti, Ageneotettix deorum, Drepanopterna femoratum, Amphitornus coloradus,* and *Metator pardalinus.*

STRUCTURE

EXTERNAL

The grasshopper's body, like that of other insects, has three main parts—head, thorax, and abdomen. These parts, and the soft inner parts of the body, are protected by tough covering plates much like those of crabs and lobsters. There is no internal skeleton. Flexible membranes allow movement of the main parts of the body and their appendages, and hold the covering plates together.

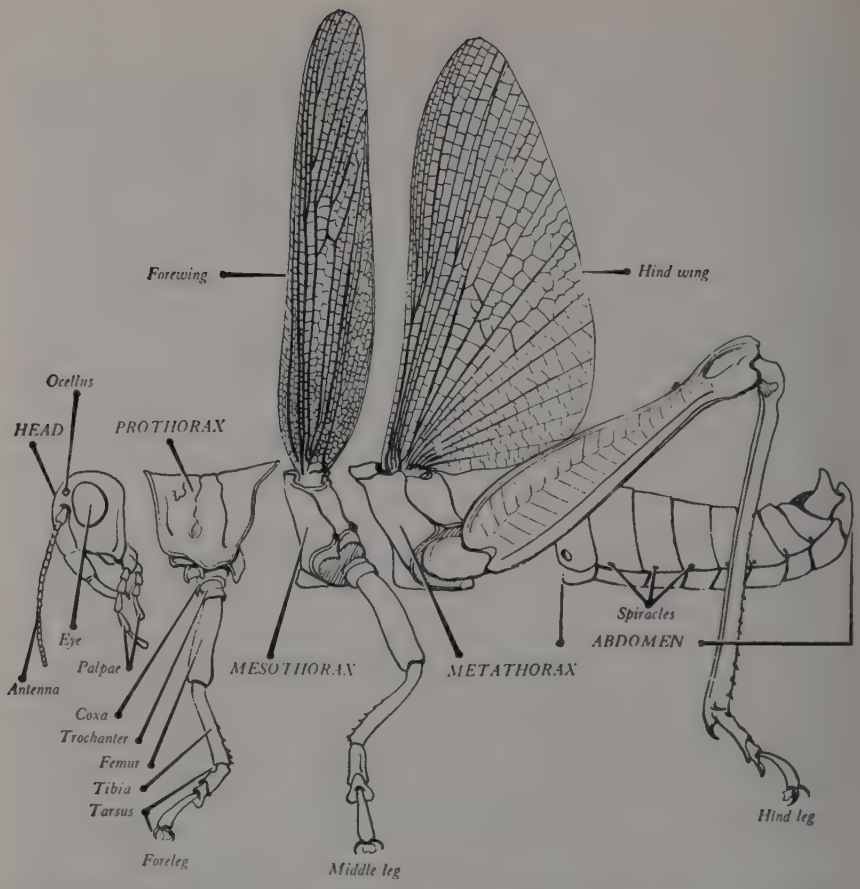
On the head are eyes (two kinds), antennae, and chewing mouth parts.

The two large eyes on the sides of the head are the principal visual organs. They are called compound eyes; each consists of thousands of little eyes that work together to form a single picture in the grasshopper's brain. Their placement and outwardly curved surface enable the grasshopper to see forward, backward, and sidewise for considerable distances.

Besides the 2 large compound eyes, grasshoppers have 3 small single eyes. Two of these are over the antennae. The third is halfway between and just below the other two. Scientists differ over the functions of the single eyes. Some say they are for seeing objects only inches away. Others insist they merely measure light intensity and act as a sort of thermostat to regulate nerves and muscles of the compound eyes.

The antennae, or feelers, are slender, jointed appendages. The grasshopper examines its food with them before it begins to eat, and takes great pains to keep them clean. The cleaning is done by lowering the head, placing a front foot on a feeler, and pulling the feeler slowly upward by raising the head.

Closeup of part of the rangeland shown on the preceding page. Note the grass stems, cut by grasshoppers, that have been washed by rain into the gully in left foreground.



A grasshopper's body has three main parts—head, thorax (divided into prothorax, mesothorax, and metathorax), and abdomen. The wings and legs are attached to the thorax.

The grasshopper's mouth is on the lower front part of the head. Its main parts are 2 lips and 2 powerful jaws. The jaws are edged with sharp teeth. The upper lip is a flexible flap that allows the jaws to mesh beneath it. On both sides of the mouth and on the lower lip are slender jointed appendages, called palpi, which are used in tasting food.

All the organs of locomotion are attached to the thorax, which is divided by plates and membranes into three sections called prothorax, mesothorax, and metathorax. The prothorax, next to the head, bears the front legs. The mesothorax, the middle section, bears the second pair of legs and the front wings (upper wings). The metathorax is the hind section; attached to it are the hind legs and the hind wings (underwings).

The upper wings are thicker than the underwings. They serve to protect the more delicate and more transparent underwings, which are folded like a fan. When a grasshopper flies, the upper wings serve the same purpose as the wings of an airplane, and the lower wings become the propeller.

Some kinds of grasshoppers are strong fliers, others fly only short distances, and some have such poorly developed wings that they cannot fly at all.

The front legs and feet are used in manipulating food. The insect feeds on a section of a leaf by holding it between the front feet—a foot on each surface—and scalloping the margin with its sharp jaws. In eating the ends of round, slim stems, it uses the feet to hold the stems and to push the ends into the mouth.

All three pairs of legs are used in walking. The long, powerful hind legs enable grasshoppers to jump long distances and to catapult themselves into the air when starting to fly.

The abdomen is divided into segments, which are held together by folded elastic membranes. It can be expanded to allow more space for food and to allow the female more room for developing eggs. While laying eggs, the female extends the abdomen to 2 or 3 times its usual length. The abdomen is also an air pump. By expanding and contracting, it pumps air to all parts of the body.

The last segments of the abdomen are modified to form mating organs. The abdomen of the female ends in four hard, movable prongs, which function like a miniature post-hole digger when the female is laying eggs and inserting them in the ground.

INTERNAL

Within the external hard walls of the body, and protected by them, are the digestive, circulatory, respiratory, and nervous systems and the reproductive organs.

The digestive system consists of mouth, esophagus, salivary glands, crop, gizzard, stomach, intestine, and rectum. Digested food is absorbed by the walls of the stomach and passed into the blood stream.

The circulatory system is a simple affair. The heart is a long, pulsating tube in the upper part of the body cavity. Blood enters the tube, and some passes out through valves in the sides. Most of the blood is pumped from the heart into the head cavity; it then flows through the body, bathing all internal organs, and again goes through the heart. The blood, which is green, carries some oxygen and carbon dioxide in solution. It distributes food to the body cells and takes waste products away from them.

The respiratory system has no lungs for forcibly inhaling oxygen and expelling carbon dioxide. Instead, the grasshopper is equipped with an air-conditioning system that carries oxygen directly to most parts of the body and allows much of the carbon dioxide to escape. Openings, called spiracles, are located on the sides of the grasshopper—2 pairs on the thorax and 8 pairs on the abdomen. The spiracles, which can be closed or opened, lead into flexible tubes that divide and subdivide into thousands of ever-smaller branches. The branches extend to all parts of the body. Air is partially circulated by the contraction and expansion of the abdomen, which works like a bellows. Air containing some carbon dioxide is squeezed out of the elastic breathing tubes when the walls of the abdomen contract, and fresh air enters when they expand.

The nervous system consists of a nerve chain that extends through the lower part of the body cavity. The head end is largest, and forms a primi-

288990°—54——3

tive sort of brain. The nerve chain is divided into links called ganglia. Each link has branch nerves that direct the activities of organs associated with it.

Reproductive organs are in the abdomen. Male organs consist of an unpaired testicle, paired seminal ducts, and mating apparatus. Female organs include paired ovaries and oviducts, and vagina. Ovaries containing undeveloped eggs are comparatively small, but the ovaries increase greatly in size as egg-laying time approaches; by the time egg laying begins they occupy a large portion of the abdominal cavity.

Spaces within the grasshopper's body not occupied by vital organs or blood are filled with a fatlike material. This is thought to have some excretory functions, but its main purpose is to provide material for the growth of eggs and sperms.

DEVELOPMENT

Crop grasshoppers in Northern States have a single generation each year. Eggs are laid in the summer and fall, remain in the ground during winter, and hatch in April, May, and June. None of the crop species are able to survive the winter except in the egg stage. However, there are several range species of little economic importance that hatch in the fall and pass the winter in the half-grown stage. When the immature hoppers are seen moving about during warm spells in winter, or in early spring, they are often believed to be newly hatched, and erroneous reports that grasshoppers are hatching may be circulated.

In the South the migratory grasshopper is not limited to a single generation. There are frequently two generations in Kansas, and usually three in Arizona. The two-striped and differential grasshoppers are limited to a single generation in the South just as they are in the North.

HATCHING

The young grasshopper has its beginning within the egg buried in the ground, where its growth is governed by temperature, moisture, and the hereditary forces that determine the particular kind of grasshopper it is to become. When the swelling embryo finally breaks the eggshell and squirms free, it is still wrapped in a cellophane-like envelope that holds the legs and feelers tightly against the body. In spite of this handicap it shows remarkable ability to wiggle its way upward through the soil. Even if the egg pod has been covered with several inches of drifting soil, the young grasshopper usually makes the grade. Ordinarily the distance to the surface is not more than an inch.

Once the trail has been broken by the first grasshopper to hatch from the egg pod, the others escape easily and quickly. Immediately on reaching the surface the young grasshopper sheds the swaddling membrane that hindered its movements but protected its soft body while it struggled upward through the soil. Now for the first time the legs, feelers, and mouth parts are free, and the baby grasshopper is ready to walk, jump, and eat. Its color at first is white, but after several hours in the sunlight it takes on the characteristic color pattern of the species to which it belongs.

MOLTING

In contrast to many other insects, newly hatched grasshoppers closely resemble their parents, except for size and lack of wings. They have no larval, or maggot, stage, as do flies, and they do not spin a cocoon or enter a resting stage before becoming adult.

The young grasshopper advances toward maturity by growing a new body covering and shedding the old one. The old covering splits down the back to permit the emergence of the slightly larger and more fully developed grasshopper. This process, called molting, occurs 5 or 6 times over a period of 40 to 60 days. It is controlled by hormones and other internal secretions. Where grasshoppers are numerous, the hollow castoff skins are often mistaken for dead grasshoppers, and are the basis for misleading reports that grasshoppers are "dying by the millions."

The last molting process is an event that any nature lover will find absorbingly interesting. It is a common sight on warm days in the early summer when grasshoppers are abundant and first getting their wings. The grasshopper about to acquire wings hangs head downward, gripping whatever it is resting on with all six feet. The old skin then splits down the back and the emerging adult, aided by gravity, slowly pulls its feelers and legs from their encasements. As soon as it is free, it turns and faces upward so that the crumpled damp wings will hang straight down as they unfold. Slow, pulsating movements of the body force blood and air into the wings until they are inflated. Then the wings begin to dry, stiffen, and take on their normal colors. Finally the underwings are neatly folded and tucked under the protecting harder and narrower upper wings.

Time required for actual emergence varies from 1 to 3 hours at each molt, but considerably more time is spent in preparing for emergence and recovering from it. Grasshoppers rest quietly without eating for about a day before molting. After molting, they sit around for several hours waiting for the external body parts to harden. This period of no feeding is often responsible for poor initial results when vegetation is sprayed with stomach-acting insecticides, but most poisons remain effective long enough to kill when feeding starts again.

THE ADULTS

When wing development is completed, grasshoppers become adult and do not molt again. Their activities are no longer confined to feeding and ground locomotion. Most species are now able to fly, and all become increasingly concerned about reproduction.

REPRODUCTION

Males and females of most species remain together in about equal numbers and mate when sexually mature. One mating fertilizes several batches of eggs.

In some species, such as the clear-winged grasshopper and the long-winged plains grasshopper, males and females gather in large numbers on well-defined breeding grounds for mating and egg laying. A breeding ground may cover several acres or only a few square feet. Whatever its size,

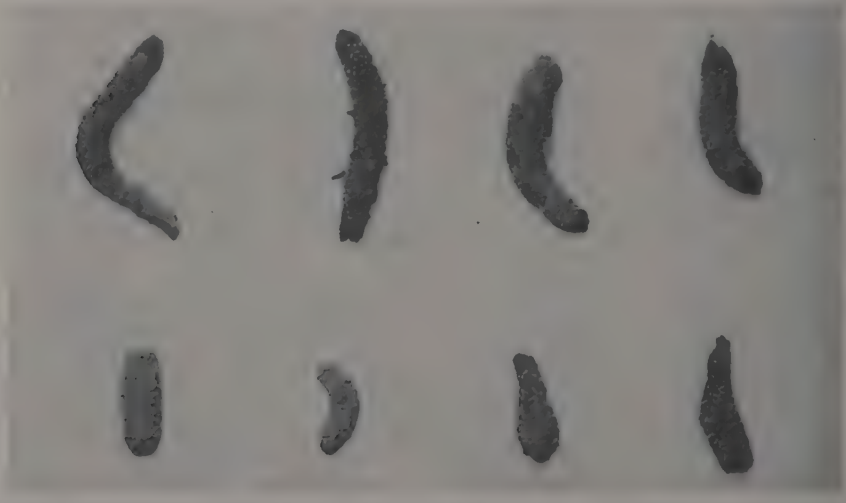
it is a scene of feverish activity when egg laying is in full swing. The males stay on the area, or close to it. They search constantly for mates, and sometimes outnumber the females 10 to 1. The females shuttle back and forth between the breeding ground and their feeding sites. When they fly in, they immediately mate or lay eggs, or both; then they leave to resume feeding.

Incredible numbers of eggs are sometimes found in breeding grounds after egg laying for the season is completed. E. D. Ball, while studying the clear-winged grasshopper in Utah, found an infestation where they averaged 25,000 to the square foot, or 1 billion to the acre, over 20 acres of egg beds.

Farmers and ranchers can control these species more easily if they watch for mating grasshoppers and mark the egg beds. They can spray a few acres immediately after the grasshoppers hatch, instead of treating much larger tracts after they disperse.

Mating and egg-laying habits are different in the species that do not have well-defined breeding places: Mating usually takes place well in advance of egg laying, and the egg laying is preceded by a diligent search for a proper spot in the soil. A female ready to lay eggs probes the soil or sod here and there until she is satisfied that "this is the spot," then goes to work. The hard, sharp prongs of the ovipositor are started into the ground by pressure from above. The ovipositor gets a good bite on the ground, then digs its way downward, pulling the lengthening abdomen after it. The expanding and contracting valves of the ovipositor push the soil sideways to form a firm-walled tunnel for storage of eggs. The depth of the tunnel is determined by the length of the fully extended abdomen.

When the tunnel is completed, egg laying begins. The valves of the ovipositor open, and the eggs, enveloped in a thin, sticky substance, start coming out. The abdomen gradually shortens as the eggs fill the tunnel. When all the eggs are laid, they are covered by a final shot of liquid glue. The hard-



Egg pods of eight kinds of grasshoppers.

Two-striped grasshopper: Female laying eggs. 2× natural size.

ened glue holds the eggs together and protects them from drought or excessive moisture. The mass of eggs is called an egg pod.

When eggs are laid in bare ground, the female usually takes great pains to plug the hole left at the surface when the abdomen is withdrawn. In some species the female does this by scratching with the hind legs; in others she does it by brushing with sideswipes of the abdomen.

The number of egg pods laid by one female varies according to the species, the food supply, and the weather. Records of egg laying by individual grasshoppers show the following maximum numbers of pods laid: A migratory grasshopper, 21 pods; a two-striped grasshopper, 12; and a differential grasshopper, 8.

The number of eggs in each pod varies slightly in the same species and widely among different species. Egg pods of the clear-winged and the migratory grasshopper usually contain 15 to 20 eggs, and those of the differential and the two-striped grasshopper, 50 to 75. Some range species have only 2 to 6 eggs to the pod. A few species deposit eggs loosely without gluing them into a pod.

For any species the shape and appearance of the pods, the arrangement of eggs within a pod, and the structure and color of the eggs are always different (sometimes strikingly so) from those of any other species. Eggs of medium-sized grasshoppers resemble kernels of rice in size and shape. Colors vary from creamy white to greenish yellow, light tan, dark brown, and reddish brown.

Knowing where grasshoppers prefer to lay their eggs is highly important in making surveys and planning control. The migratory grasshopper lays its eggs throughout grain, alfalfa, and other uncultivated crops and also in idle land, field margins, fence rows,

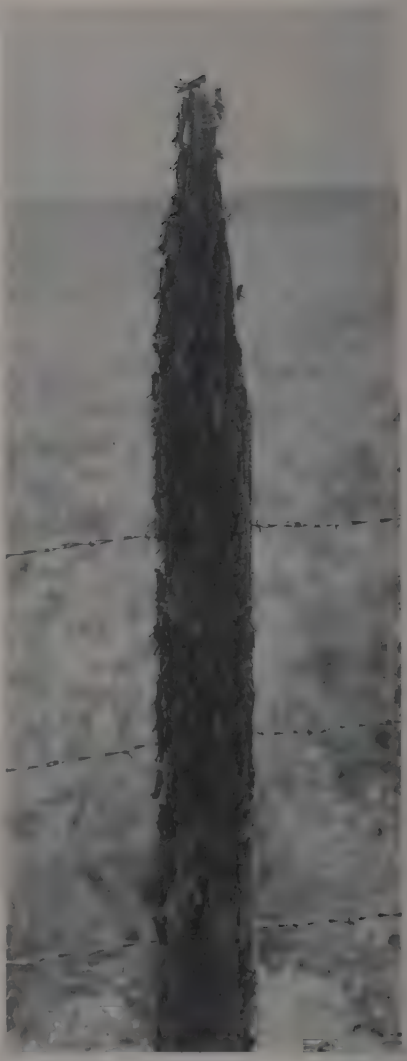
ditchbanks, roadsides, and rangeland. The differential and the two-striped grasshopper lay few eggs within cropped fields; they prefer sod or weedy ground bordering the crop upon which they are feeding. The clear-winged grasshopper lays its eggs almost entirely in the crowns and roots of grasses.

FLIGHTS

All grasshoppers with well-developed wings do some sporadic flying. Short flights are made in search of mates, food, or more comfortable situations.

Mass flights (swarming) take place when grasshoppers become extremely abundant. Why do they take place? One explanation is that the main objective is to obtain food. It is true that grasshoppers often leave drying vegetation and fly upwind, only a few feet above the ground, toward green corn, alfalfa, or other succulent vegetation. The moisture or odor coming from the greener vegetation may attract the grasshoppers to it.

But this explanation does not apply to higher, long-distance mass flights, which often originate where food is plentiful and end where it is scarce. A more reasonable explanation is that such flights are prompted by an urge to escape uncomfortable surroundings and by a response to the herd instinct. They usually originate where vegetation is short, and prevailing midday air temperatures are over 75° F. Under such conditions ground-surface temperatures range from 100° to 135°. Grasshoppers like temperatures up to 110°, but try to escape more intense heat by climbing vegetation or seeking shade. When the ground temperature is 135°, a grasshopper can find a place



When heat is intense on the ground, grasshoppers climb. Here they cluster on a post.

40° cooler by climbing 2 inches up a blade or stem of grass in direct sunlight or a still cooler spot by seeking shade. In hot weather it is common to see grasshoppers clustered on vegetation, as high as they can get, and on the shady sides of fences, telephone poles, and buildings.

When grasshoppers are numerous, their feeding rapidly reduces the height and density of vegetation. Soon there is little to climb on, and in most places no shade. Grasshoppers then start taking to the air to cool off. This is a wise move, because 15 minutes at 135° F. will kill them.

The first flying of the season is done by a few individuals that mill about during the hottest part of the day and then settle down close to where they took off. These early fliers excite others, and within a few days nearly all adults are doing some flying, but they still act as individuals, fly in no particular direction, and settle back in the same locality. Then comes a day when, for no obvious reason, the individuals become a swarm that flies in formation, takes off for parts unknown, and thereafter acts as a unit. Each grasshopper is excited to action by those nearest to him. When a leader starts off, or changes direction, all others follow without hesitation.

Swarms fly only when conditions are favorable. They are most likely to take off when the air temperature for the day first reaches 75° to 80° F. and there is just enough breeze to ripple grass or crops. If there is no wind, or if it is blowing more than about 10 miles an hour, they do not fly even though temperatures are favorable. They remain grounded during cool, cloudy weather.

Swarms in the air plummet to earth when storm clouds darken the sun or when there is a sudden drop in temperature. This reaction may explain the finding of great numbers of grasshoppers embedded in glaciers. The conjecture runs as follows: Thundershowers obscured the sun and cooled the air; high-flying swarms dropped suddenly onto mountain peaks and glaciers; those that landed on glaciers were frozen, and were preserved in cold storage for hundreds of years.

Swarms flying on days when the weather remains warm and clear drift slowly to the ground in the late afternoon.

After a swarm has made several flights, it is no longer greatly influenced by food or shade. It feeds ravenously between flights, but, as long as the migratory urge persists, it leaves lush vegetation and plentiful shade whenever wind and temperature again become favorable for flying.

As females become heavy with eggs, they start dropping out of the swarms. When all are ready for egg laying, flights end.

The direction and height of flight vary with different species. Swarms of *Melanoplus rugglesi* take off into the wind like an airplane and buck the wind in low rolling formation, 5 to 100 feet above the ground. When a large swarm is passing, the noise of wings beating against the breeze sounds like the roar of a distant waterfall.

Swarms of the migratory grasshopper rise against the wind, then turn and fly with it. Warm air rising from the hot ground assists their upward flight, and soon they are in the air as high as the eye can reach. Against the edge of the sun they look like specks of glittering metal. Nobody knows how high they go, but airplane pilots have reported encountering them several thousand feet above the ground. Downwind flights of grasshoppers are noiseless except for faint whispers of rustling wings.

Swarms of the clear-winged grass-

hopper fly with, against, or crosswise to the wind. They have a tendency to fly east in the morning, to mill about in all directions at midday, and to fly west in the afternoon. They fly slightly higher than *rugglesi* and decidedly lower than the migratory grasshopper.

Swarms of grasshoppers stay on the ground for days at a time in cool, cloudy, windy weather. They take off again when the weather becomes hot and clear and there is only a slight breeze.

Swarms frequently fly in the same general direction for the entire flight period, even though they come to the ground from time to time. This fact has led some persons to proclaim that grasshoppers have an instinct to go in a particular direction, and that they will stay on the ground until the wind is in their favor. A more logical explanation can be found in the weather pattern in the locality where flights are in progress. When it is hot, winds tend to blow in the same direction day after day; when it is cool, they blow in another direction. When minor changes in wind direction occur, swarms fly accordingly. I have seen them flying in three different directions in as many days. I have also seen swarms stay on the ground during cool weather even though the wind was favorable for them to continue in the direction they had been going.

The distance traveled by swarms depends on their flying habits and on how much favorable flying time they have. Those flying upwind obviously don't get as far as those flying downwind. The speed of a grasshopper flying in nearly calm air is around 10 miles an hour. If it is flying against an 8-mile wind, its advance, in relation to the ground, will be at a speed of only about 2 miles an hour. Swarms of *rugglesi* flying upwind have been known to advance 2 to 5 miles in a day and 50 to 100 miles in a season. On the other hand, swarms of the migratory grasshopper are accelerated by the wind, for they fly with it. They have been observed to travel 25 to 50 miles in a day and hundreds of miles in a season. In 1938 swarms of this species flew from central South Dakota to central Montana, a distance of about 500 miles, in 3 weeks. Between 1874 and 1877 great swarms of the Rocky Mountain grasshopper originated in Montana and migrated eastward to the Mississippi Valley and southward to Texas. Each completed the migration in a single season.

Because of their habit of flying with, against, or crosswise to the wind, swarms of the clear-winged grasshopper generally end the season not far from where they start flying.

The number of days favorable for flying and the number of hours in flight each day are much greater in hot summers than in cool summers. Flights of all grasshoppers are more frequent and cover greater distances in hot summers.

A few kinds of grasshoppers do some flying at night during unusually hot weather, and are attracted to light. The numbers in such flights are usually small, but in 1932 I witnessed a night flight of great magnitude. It caused excitement in widely separated towns and cities. The species in flight was *Pardalophora haldemanii*, one of our largest grasshoppers. It has a wingspread of nearly 4 inches and a heavy body 2 inches long. It is a range grasshopper that has never been reported particularly abundant or destructive.

I noticed them bumping against the windshield of my car shortly after dark on a hot night in July as I drove west toward Chamberlain. S. Dak. When I arrived in town, everyone was talking about the big grasshoppers, which were everywhere. They were clustered on the porch of the hotel and flying in the lobby, hiding behind bottles in drugstores, and driving patrons and waitresses frantic in eating places. They were massed in greatest numbers around street lights, store windows, and filling stations. Their crushed bodies littered sidewalks and pavements. Those that survived their night in town took off toward the sun the following morning.

That day I drove 225 miles west and stopped at every town along the way. Everyone I talked with had the same story of big grasshoppers that had been in the town the night before. Crushed grasshoppers on the sidewalks were of the same kind as those seen at Chamberlain. That evening in Rapid City I read in a newspaper that similar flights had occurred in Nebraska, about 100 miles southeast of Chamberlain, and that street lights had been turned off in some towns to discourage the night-flying hordes.

Why this one species, of the many present, suddenly got the urge for the bright lights, on this one night, is not known.

CANNIBALS

Grasshoppers feed greedily upon their own crippled and dead, but seldom attack grasshoppers that are alive and of sound body. It is common to see them massed on highways eating grasshoppers crushed by passing cars. Once I stopped to watch such a gathering and saw something unusual—one big grasshopper attacking and killing an equally husky companion in a matter of minutes. Adult lubber grasshoppers were pushing and kicking each other in a struggle to get their share of the carcasses. I became interested in a grasshopper that got kicked or shoved aside every time it tried to get in on the feast. Seemingly irritated beyond restraint by such treatment, it suddenly went berserk. It jumped astride the nearest competitor, clasped it tightly with its middle pair of legs, and rode it like a cowboy on a bucking bronco. The ridden grasshopper soon tired, whereupon the aggressor chewed fast and furiously into the head of its victim. This must have severed its brain, for in a few minutes it stopped struggling and was quickly devoured by its attacker and others that moved in to share the kill.

MANEATERS

Grasshoppers frequently bite when picked up, and sometimes they attack even when unmolested. I found out about their willingness to attack as I sat with another entomologist in a South Dakota cornfield that was being invaded by flying two-striped grasshoppers. If we were sitting perfectly still when they landed, they started for us instead of the corn. Crawling onto any exposed skin, they bit ferociously and sometimes drew blood. They jumped away when we moved, but came sneaking back when we sat motionless for several minutes. We were perspiring profusely, and decided that grasshoppers preferred sweat-soaked skin to green corn.

Of course we wondered what would happen if the grasshoppers were to find

us helpless and unable to scare them away. Several years later I found a partial answer in an old letter written by General Alfred Sully, U. S. A., from Sioux City, Iowa, and published in the Saint Paul Press on June 21, 1865. He wrote:

> The only thing spoken of about here is the grasshoppers. They are awful; they have actually eaten holes in my wagon covers and in the 'paulins that cover my stores. A soldier on his way here lay down to sleep in the middle of the day on the prairie. The troops had been marching all night. His comrades noticed him covered with grasshoppers, and woke him. His throat and wrists were bleeding from the bite of these insects. This is no fiction.

NATURAL ENEMIES

Grasshoppers have many natural enemies. Without them, the control of grasshoppers by man would be much more difficult and probably impossible.

Some attack the immature and adult stages; others prey on the eggs. Some attack at one season, some at another. In combination they carry on destructive action that never ceases.

Among the more powerful enemies are flesh flies, tangle-veined flies, bee flies, blister beetles, ground beetles, spiders, hairworms, rodents, birds, and diseases.

Flesh flies (Sarcophagidae) deposit active maggots on grasshoppers, even while the latter are in flight. The tiny maggots work their way into the body and feed on its contents; they leave the more vital organs for final feeding. When flesh flies are abundant, they frequently kill large numbers of grasshoppers by midsummer, and infest so many of those remaining that egg laying is greatly reduced. Farmers who are told about flesh flies, and shown how they dart and hit grasshoppers when the latter jump or fly, enjoy seeing the pests get plastered with maggots. I have known some to spend half an hour making grasshoppers jump so the flies would hit them.

Tangle-veined flies laying eggs on a fence post. The maggots that hatch from these eggs bore into grasshoppers.

Tangle-veined flies (Nemestrinidae) are similar in color to honey bees but slightly smaller. Unlike flesh flies, the adults pay no attention to grasshoppers. Upon emerging from the ground the

egg-laden females fly to the nearest wooden fence post or other upright object and start laying eggs in cracks and holes in the wood. Eggs are laid in remarkable numbers and at unbelievable speed. One female was observed to lay 1,000 eggs on a single post in 15 minutes. Another female, confined in a pillbox, laid 4,700 eggs in 7 hours. Eggs hatch in about 10 days, and the tiny maggots are blown away by the wind. Just how they find grasshoppers is a mystery, but the large numbers of grasshoppers in which they are found proves that many are successful. When a maggot gets on a grasshopper, it bores into its abdomen, lives on its contents, and thus eventually kills it. You can tell tangled-vein fly maggots from flesh fly maggots by the long breathing tubes that they attach to the grasshopper's air-circulating system. When the maggot is full grown, it forces its way out of the grasshopper, and goes into the ground. It changes to a pupa the next spring, and the adult fly emerges several weeks later. There is only one generation a year.

Bee flies (Bombyliidae), blister beetles (Meloidae), and ground beetles (Carabidae) lay their eggs in the soil close to grasshopper egg pods, or even in them. Maggots hatching from the eggs work their way into the egg pods and usually consume all the eggs of the pods they enter. These predators have been known to destroy 40 to 60 percent of all grasshopper eggs over considerable acreages.

Spider webs trap surprisingly large numbers of immature and adult grasshoppers. Even the largest grasshopper is securely bound with silken strands within a few seconds after it becomes entangled in a web.

In some States hairworms are common parasites of grasshoppers. Hairworms are long, whitish, and extremely slender. They are frequently found coiled within the body cavity of living grasshoppers. Grasshoppers thus infested may live 1 to 3 months, but are retarded in their development, and the females are rendered sterile. When the worms complete their growth in the grasshopper, they kill it by forcing their way through the body wall. They then enter the ground.

Ground squirrels, field mice, and other rodents eat grasshoppers and dig in the ground for their eggs. No figures are available on the percentage of eggs destroyed by rodents. It must be high, since evidence of their digging can be seen wherever grasshopper eggs are abundant.

The Fish and Wildlife Service, United States Department of the Interior, has found that birds play an important part in the natural control of grasshoppers. All birds, except the strictly vegetarian doves and pigeons, feed on grasshoppers. Some eat the eggs after scratching them from the ground. Birds are of great value in holding grasshoppers in check when the latter occur in moderate numbers, but they cannot prevent outbreaks.

It is often asserted by nature lovers that grasshopper outbreaks are due to the decrease in the number of game birds and song birds. If their reasoning is correct, it becomes difficult to explain the severe grasshopper outbreaks that were common in the Great Plains 50 to 100 years ago. Game birds were far more plentiful then than now, and the natural distribution of song birds had not been disturbed by agriculture.

Fungus and bacterial diseases destroy great numbers of grasshoppers, and sometimes terminate outbreaks. Unfortunately the dry conditions that usually prevail in grasshopper years are not favorable to the development of these diseases. Many attempts have been made to control grasshoppers by artificially culturing and distributing grasshopper-disease organisms. Nearly all have failed. There is still hope, however, that research may develop new and more effective methods of using germ warfare against grasshoppers.

EFFECT OF WEATHER

Newly hatched grasshoppers, like most young animals, are delicate creatures. They are difficult to raise, even in the laboratory, where the most favorable conditions known are provided. Unless they feed and their digestive system starts functioning normally soon after hatching, many of them die within a few days. Temperature and rainfall are extremely important during this critical period.

TEMPERATURE

Grasshoppers are sun worshipers. They respond to changes in temperature like mercury in a thermometer. Like ourselves, they seek warmer places when the air temperature falls a few degrees below 68° F. At such times they crawl into any shelter they can find. Fields that were swarming with grasshoppers at midday may appear to be free of them an hour after sundown. When the morning sun warms the air and ground, the grasshoppers crawl slowly from their hiding places. They take positions broadside to the sun and seem to revel in its warmth. In this position their body temperature is 10° higher than when facing the sun. They start moving about when the air temperature reaches 68° to 70°, and are active during the greater part of the day in ordinary summer weather. Just before sundown they again arrange themselves broadside to the sun, and sit motionless until it drops below the horizon.

Should you ever happen to be where grasshoppers are clustered thickly on the ground in the late afternoon, you can test their response to temperature and light. Approach them slowly, let your shadow fall across them, and stand still for several minutes. They will crawl out of your shadow to the warmer ground around it. You will see your shadow outlined by densely massed grasshoppers.

Grasshoppers can live in a wide range of temperature. It takes 16 hours of exposure at −22° F. or 10 minutes at 140° to kill the eggs. Adults are killed by 24 hours of exposure at 14° or 15 minutes at 135°.

Temperature has an important effect on the number of eggs laid. High temperatures during the summer and fall bring early maturity and provide a long period for egg laying. Low temperatures have the opposite effect.

If hatching is brought about prematurely by abnormally high temperature early in the spring, and this is followed by weather that is too cold for general feeding (70° F. and below), great numbers of the newly hatched hoppers die. Unseasonably cool weather late in the spring after the normal hatch has taken place may also reduce the numbers. On the other hand, if the hatching is followed by several weeks of continu-

Grasshoppers killed by a fungus disease.

ously warm, dry weather, the young hoppers get off to a healthy start. Nearly all that hatch survive the critical early stages.

Winter weather has little effect on grasshopper abundance. Nearly all sound eggs that are in the ground at the beginning of winter will hatch the following spring.

RAINFALL

Periods of a week or more of continuously cloudy, wet weather, with the relative humidity close to the saturation point, are favorable for the development of bacterial and fungus diseases. Prolonged wet weather, not the total amount of rainfall, is what counts. A fall of several inches of rain in a

day or two, followed by bright sunshine, has little effect, but the same amount, or even less, scattered through a week of cloudy weather may start an epidemic of grasshopper disease.

Heavy rains during or immediately after the hatching period may kill the young hoppers by washing them into streams or embedding them in wet soil.

Extreme drought is detrimental to grasshoppers. Eggs in some types of soil cannot hatch if the soil is dry. They may become so shriveled that they fail to hatch when the soil is moistened. Drought may also reduce plant growth to such an extent that grasshoppers starve. If they survive a period in which they get little food, their egg production may be greatly reduced.

WEATHER COMBINATIONS

Maximum increase in grasshopper numbers would result from a season having these characteristics: Cool, wet weather during the early part of the spring to prevent premature hatching and to insure an adequate food supply after hatching takes place; several weeks of continuously warm, dry weather late in the spring to cause complete hatching and provide best feeding conditions; a hot summer with sufficient rainfall to maintain an ample food supply, but with no wet periods long enough to stimulate grasshopper diseases; and a late fall to insure maximum time for egg laying.

Heavy mortality of grasshoppers would result from a season having these characteristics: Weather warm enough early in the spring to cause considerable premature hatching, followed by temperatures low enough to prevent normal development; a short period of hot weather late in the spring to insure complete hatching of the remaining eggs, followed by long periods of cloudy, wet weather favorable for grasshopper diseases; a cool summer and an early fall to delay maturity and shorten the time for egg laying.

OUTBREAKS

During grasshopper outbreaks a frequent and natural question is, "Where did they all come from?" To understand the wide variations in numbers, one must be aware of the potential reproductive capacity of grasshoppers and the many factors that check it in nonoutbreak years.

The female migratory grasshopper has been known to lay 400 eggs in a single season. The more usual number is about 200, and perhaps only 40 eggs are laid during an unusually cool summer. Thus, without any change in the number of grasshoppers laying eggs, the number of eggs laid in an extremely favorable year may be 10 times as great as the number laid in an extremely unfavorable year.

It should also be noted that a grasshopper population made up of an equal number of males and females would remain at the same level for another year (from one season to the next) if only 2 adults develop from the eggs laid by each female. Suppose that, on an average, each female lays 200 eggs. Suppose that 198 are destroyed, or that all hatch but 198 of the young grasshoppers die before maturity. The population would remain the same.

If, instead of only 2 surviving adults,

there are 4, 6, 8, 10, or perhaps 50, then the adult population the following year would be increased 2, 3, 4, 5, or 25 times.

Let us speculate a moment and see what would happen if all eggs hatched and developed into adults. If at the start there are 50 adults to the square yard, the 100-fold increase would result in 24,200,000 grasshoppers, with a combined weight of 8 tons, to the acre. Fortunately for us, any such rate of increase is prevented by natural enemies, weather, and food limitations.

Most outbreaks are preceded by several years of gradual increase in grasshopper numbers and by a year that is unusually favorable. This results in a pyramidal increase—and an astonishing number of grasshoppers the first year of the outbreak.

At the low point between outbreaks, less than one grasshopper to the square yard is generally present in crops and other favorable habitats. When conditions become slightly more favorable, there may be two to the square yard. Then a year may come when numbers are doubled; there will be four to the square yard, which is not enough to injure crops or attract attention. The following year the population may again be doubled; there will be eight to the square yard, which is enough to cause some injury, but not enough to cause much comment. Conditions the next year may be more favorable than in previous years; instead of being doubled, the numbers are tripled or quadrupled; there will be 24 or 32 grasshoppers to the square yard, which is enough to injure crops severely and to be considered an outbreak. An increase of 10 times would result in 80 grasshoppers to the square yard—not an unusual number during very severe outbreaks. With such numbers present, crops and native vegetation may be entirely devoured if man-devised control methods are not employed.

When an outbreak subsides, there is generally a sudden drop to nearly normal numbers. This usually occurs following a year when weather conditions were highly unfavorable for the survival of young grasshoppers and for egg laying, and at a time when parasites and predators have reached maximum abundance.

Little-understood physiological characteristics of the grasshoppers themselves may also be responsible for unusual increases in grasshopper abundance. Some kinds of rodents periodically increase to enormous numbers and then almost disappear. This is also true of grasshoppers. Species that have remained unnoticed for years may suddenly acquire greater reproductive capacity, larger size, and greater inclinations to migrate, while associated species show no changes in fecundity, appearance, or habits. Whether this is due to combinations of external influences particularly favorable to some species but not to others, or to inherited characteristics, is a question debated by scientists.

CONTROL MEASURES

Start to control grasshoppers whenever they become noticeably abundant. Don't wait for them to damage crops or range. Early action means less injury and less work. A "wait and see" attitude can mean serious losses and more acres needing treatment later in the year.

Do a complete job. Don't be content with protecting the current year's field crops and range forage. A complete cleanup in 1 year costs less than repeating halfway measures for several years. If all local infestations of 5 or more grasshoppers to the square yard are reduced to less than 1, they will remain harmless for several years.

Insecticides are the major weapon, but slight modifications in tillage and seeding practices may sometimes greatly reduce the number of acres needing treatment with chemicals.

SPRAYS AND DUSTS

Bait made by mixing arsenic, sodium fluosilicate, or some other poison with bran or bran substitutes was the standard weapon for half a century. As a result of recent research and farm tests, baits have been almost entirely replaced by new insecticides that are applied directly to grasshoppers or to vegetation they are likely to eat. Some of these new insecticides are so potent that 2 ounces evenly distributed over an acre will kill most, if not all, of the grasshoppers present. They kill in two ways—by contact and through the stomach. If a grasshopper escapes being hit, it is killed by its first meal of poisoned food.

The new insecticides, applied either as sprays or as dusts, have many advantages over baits. Success with baits depends on the habits of the grasshoppers and on plant conditions. Some kinds of grasshoppers gorge themselves with bait. Others hardly touch it. Some refuse it entirely. When bait-feeding species predominate in sparse vegetation during dry weather, kills with bait sometimes reach 90 to 95 percent. In dense, succulent vegetation such as irrigated alfalfa, kills seldom exceed 75 percent regardless of the species present. Kills of 75 to 95 percent prevent serious damage to most crops and range, but they frequently allow grasshoppers to survive in such numbers that control must be repeated the next year. In seed alfalfa and other legumes, almost 100-percent control is needed to prevent injury to blooms and seed pods. Injury can be severe when only a few grasshoppers are present.

Kills with the best sprays and dusts usually reach 90 percent in 3 days and continue for several weeks. Infestations of 25 to 100 grasshoppers to the square yard have frequently been reduced to less than 1 in 10 square yards. Such kills give complete protection to crops and range. If spraying or dusting is done early enough to prevent egg laying, no further control will be needed for several years unless grasshoppers move in from untreated land.

Sprays and dusts have other advantages over baits. Standard dosages control infestations regardless of the number of grasshoppers present. Bait dosages must be varied according to numbers present, which can be determined only by time-consuming surveys of the area to be treated. Sprays and dusts are more stable in price than bran, and cost less to transport and store. Bran for bait is in direct competition with bran for livestock, and the price frequently soars when large quantities are needed for grasshopper control.

Aldrin, chlordane, dieldrin, heptachlor, and toxaphene are insecticides that have been approved in recent years for controlling grasshoppers. Dieldrin

may be used to control these insects on alfalfa, flax, wheat, barley, or wasteland. Methoxychlor should be used on fruits and vegetables.

Great progress is being made in developing new insecticides—and insecticides other than those now approved may be recommended for grasshopper control in the future. Keep in touch with your State entomological agencies for up-to-date information.

Formulations and Dosages

The insecticides recommended in this bulletin for grasshopper control may be applied as dusts, but sprays give higher initial kills, continue to kill over a longer period, and require less insecticide to the acre.

Dusts are sold in different strengths, and should be purchased ready-mixed.

Spray formulations on the market include high-percentage concentrates prepared for emulsification with water or dilution with kerosene or fuel oil, and wettable powders prepared for dilution with water.

To prepare emulsions or wettable-powder sprays, mix the insecticide formulation with water in a proportion that will insure your getting the dosage (quantity of actual insecticide per acre) that is required. To determine the proper proportion, you must take into account not only the percentage of actual insecticide in the formulation, but also the amount of spray that your equipment delivers per acre.

To prepare oil solutions, mix the insecticide concentrate with kerosene or fuel oil in a proportion that will give you the required dosage.

Emulsions and solutions are less likely to clog nozzles than are wettable-powder sprays.

Emulsions are safer than oil solutions for use on tender foliage. Do not use more than 1 gallon of an oil solution to the acre.

If you wish to use a spray, select one of the insecticides and determine which of the formulations is best suited to your purpose. Determine also how much to dilute the formulation. Regardless of the formulation or dilution decided upon, the quantity of actual insecticide applied to each acre should be as follows: Aldrin, 1½ to 2 ounces; chlordane, ½ to 1 pound; dieldrin, ¾ to 1 ounce; heptachlor, 3 to 4 ounces; or toxaphene, 1 to 1½ pounds.

If you use a dust, increase these dosages by 50 percent.

When long-continued killing action is not essential, use the lower dosages for young grasshoppers in short, dense, lush vegetation and on open stands of taller growth.

Use the higher dosages when vegetation is tall and dense or when grasshoppers are adults. When it is necessary to control young grasshoppers before the main hatch is completed, the higher dosages may extend chemical action long enough to kill the rest of the hatch and thus save the cost of a second treatment.

The dosages recommended are based on performance in experiments and in general use. They should not be expected to fit the requirements of all local conditions in the many States where grasshopper control is needed. They are offered as a guide to help individuals solve their own problems. If you have any difficulties, consult

Aircraft spraying is practical when large fields are solidly infested. This plane carries 90 gallons of spray material, and can treat 90 acres in 10 minutes of flying time.

your county agricultural agent, your State entomologist, or the extension or experiment station entomologist at your State agricultural college.

Applying the Insecticide

The recommended insecticides are most effective when applied evenly at the right time and in the right place. They may be applied with ground sprayers or dusters, or by airplane.

If you operate a farm or ranch, you will need a power sprayer, power duster, or airplane. Spraying is more satisfactory than dusting, but if you have a power duster for other work it can be used in grasshopper control.

Low-gallonage, low-pressure sprayers are best. A power outfit equipped to deliver the insecticide to either side of the machine is needed for treating roadsides, fence rows, and field margins.

Applying insecticides by aircraft is a common practice and is increasing every year. Airplanes have several advantages over ground equipment. They can be used where ground equipment might injure crops, and can operate over terrain too rough or too soft for motor vehicles. The acres treated in hours by aircraft require days to cover by ground machines. Every day gained in getting the job done means less grasshopper damage. In making your choice between ground equipment and aircraft, carefully consider the size and continuity of the infestation. Use ground equipment when fields are small or when grasshoppers occur in spots a few acres in size. Such infestations are difficult to treat from the air without excess flying time and waste of insecticide. Aircraft applications are most practical and almost a necessity when large cropped fields

or extensive range areas are solidly infested.

All spraying and dusting equipment, regardless of type, should be carefully calibrated to deliver the recommended per-acre quantity of insecticide. Too little insecticide to the acre means repeating the job; too much means more money for chemicals and the possibility of dangerous residues.

Try to prevent young grasshoppers from reaching field crops. Start insecticide treatment early in the season. Look for hatching grounds in or near the fields. Look in idle lands bordering cultivated fields, and along field margins, roadsides, and canal banks. Timely spraying or dusting of weed patches and other vegetation in these places will destroy grasshoppers before they move into the fields. Spray or dust when the main hatch is completed or when the young hoppers begin to disperse. You may have to treat the crops later, to destroy more mature grasshoppers, but early attention to the sources of infestation will greatly reduce the amount of control work that may be necessary later. Grasshoppers that damage row crops usually hatch in the field margins.

To prevent grasshoppers from damaging corn, treat the margins of cornfields and adjacent infested small-grain fields when the small grains begin to mature and before the grasshoppers move into the corn.

When an entire alfalfa field is severely infested, it is ordinarily most economical to cut the alfalfa and then apply an insecticide to protect the next cutting. Spray or dust field margins, ditchbanks, or uncut strips of alfalfa where grasshoppers have concentrated.

Power sprayer in operation. The spray can be directed to either side of the road.

Weedy roadsides and fence rows are egg-laying sites for migratory and two-striped grasshoppers. The young grasshoppers often injure adjacent crops.

Grasshoppers frequently hatch in large numbers after the first crop has been harvested. Spray or dust the next crop before the new growth is more than 6 inches high.

Grasshoppers in orchard cover crops, in vegetable-field margins, or in forage crops adjacent to orchards or vegetable fields are a threat to the fruit trees or vegetable crops. If the vegetation is cut or becomes dry, they will look for succulent food, and will move to the trees or vegetables; when they are numerous, some of them are likely to make the move even if the vegetation remains succulent. Apply an insecticide before this happens.

Spray with methoxychlor if you plan to pasture or feed dairy animals, or animals being finished for slaughter, on the treated vegetation. Methoxychlor gives slower and lower kills than the other insecticides, but it prevents serious grasshopper damage, and it leaves no harmful residue. Prepare a wettable-powder spray, and apply it at the rate of 3 pounds of methoxychlor to the acre.

If you neglect early control, you will probably have to spray the fruit trees or vegetables. Use methoxychlor on these crops to destroy the grasshoppers.

Grasshoppers on the range can be controlled as economically, and with as high a percentage of kill, as those in crops. Begin control measures when hatching of the dominant species is completed, and finish before these species begin to lay eggs.

PRECAUTIONS

Most insecticides are poisonous to man and animals, but the diluted sprays or the dusts are not dangerous to handle if precautions are followed. Insecticides in concentrated form may cause acute poisoning if they get on the skin or if they are inhaled or swallowed. Handle insecticides with care and store them, clearly labeled, out of reach of children and animals. Follow directions on the container carefully.

If you swallow an insecticide, induce vomiting by taking 1 tablespoonful of salt in a glass of warm water. Repeat if necessary. Call a doctor.

Except under certain conditions, which are enumerated below, do not feed forage treated with aldrin, dieldrin, chlordane, heptachlor, or toxaphene to dairy animals or to animals being finished for slaughter, and do not allow the animals to graze on vegetation so treated. *Exceptions:*

1. You may feed, or allow animals to graze on, alfalfa or clover treated with toxaphene at a dosage of not more than 1½ pounds per acre if you allow at least 40 days between application of the toxaphene and cutting or pasturing the crop.

2. You may feed, or allow animals to graze on, alfalfa or clover treated with aldrin at a dosage of not more than 2 ounces per acre if you allow at least 15 days between application of the aldrin and cutting or pasturing the crop.

3. You may feed, or allow animals to graze on, wheat, barley, alfalfa, or wasteland vegetation treated with dieldrin at recommended dosages if you allow at least 30 days between application of the dieldrin and cutting or pasturing the crop.

4. You may feed, or allow animals to graze on, alfalfa or clover treated with heptachlor at recommended dosages if you allow at least 10 days between application of the heptachlor and cutting or pasturing the crop. If you use heptachlor at the same dosages on range grass, roadsides, field margins, canal banks, or idle lands, do not pasture the treated areas for 15 days after the application.

Bees are essential to legume-seed production. To avoid killing them, do not apply insecticides to legumes in bloom. However, if legumes in bloom must be treated to protect the seed crop, spray with toxaphene while bees are inactive—early in the morning or late in the evening. Sprays are less harmful to bees than dusts.

CULTURAL PRACTICES

Grasshoppers are controlled to some extent by tillage and seeding operations.

These operations do not eliminate the necessity of using insecticides, but they reduce the quantity of chemicals needed and make application easier.

The suggestions given here for checking grasshopper damage and numbers by tillage and seeding methods do not apply equally well to every locality. Soil, weather, and cultural conditions differ, and so do the species of grasshoppers.

Because of its habit of laying eggs throughout fields of small grain, the migratory grasshopper is the species most easily reduced by cultural practices. It is the most common grasshopper in the northern Great Plains. Soil blowing and drought are problems in this region, and must be considered in any cultivation program.

Develop a tillage and seeding program that provides grasshopper control consistent with the approved farming practices of your locality. Consult your county agricultural agent or soil

conservationist, or your State entomologist, or the extension or experiment station entomologist at your State agricultural college. When the infestation is so severe that your entire crop is threatened, it may be advisable to modify usually approved methods in some instances to take advantage of every available measure for controlling grasshoppers.

Tillage

Working the soil kills grasshoppers in several ways. It may bury their eggs so deep that the young grasshoppers cannot reach the surface after they hatch. It may bring the eggs to the surface where they are destroyed by the drying action of the sun and wind. It is also a means of discouraging egg laying, preventing dispersal, and forcing grasshoppers scattered over a field to concentrate in a small area.

Proper tillage before eggs have hatched has frequently given excellent control of light or threatening grain-stubble infestations, and has materially reduced severe infestations. Fall tillage is preferable, but spring tillage is sometimes just as effective. Tillage right after harvest will make the soil unattractive to egg-laying females, and will assist in destroying eggs already laid.

In deciding on the time of tillage and the implement to use, you should consider, not only grasshopper control, but also the effect on soil drifting, weed control, and soil moisture.

Moldboard plowing, 5 or more inches deep, followed by packing, is the best method of preventing the emergence of young grasshoppers in districts where soils are heavy and soil blowing is not a problem.

Shallow cultivation is less effective than moldboard plowing, but will destroy many of the eggs by exposing them to the sun and wind. The one-way disk is the best implement for this purpose. The duck-foot cultivator, the single or double harrow, and the one-way disk harrow are satisfactory. "Blade" tillers used in "stubble-mulch" farming are less effective than the others. Shallow tillage is most effective during dry weather, when the egg-drying effects of the sun and wind are greatest.

Grasshopper-infested grain stubble that is to be summer-fallowed should be worked before the eggs hatch. If tillage is delayed until after the young grasshoppers appear, it still can be used to prevent their moving to nearby crops. This can be done by cultivating a strip 3 rods wide around the entire field. If it is kept cleanly fallowed, the young grasshoppers can usually be held in the field for a week or two. There may be time to complete tillage operations before they escape. Tillage after the establishment of the guard strip should start next to it, and should continue until only a small block of unworked stubble remains in the center of the field. The grasshoppers will be concentrated in this small area. They can be killed with insecticides at much less expense than would be required for spraying or dusting the entire field.

Do not plow or shallow-till large tracts of sod or idle land to control any kind of grasshopper unless you intend to seed or summer-fallow the land immediately. Cultivation ruins such land for pasture and makes it subject to soil blowing. The operation is more expensive than letting grasshoppers hatch and then killing them with insecticides.

Seeding

In grasshopper years, small grains should be planted only on fall- or spring-tilled land, or on clean summer-fallowed land. Few grasshoppers will emerge from such land.

Do not drill grain into heavily infested, unworked stubble. Few eggs are destroyed by the seeding process. When the eggs hatch, the field will swarm with young grasshoppers. Immediate spraying or dusting of the entire field will be necessary to save the crop.

Early seeding is an important factor in reducing grasshopper damage. Early-seeded crops make considerable growth before grasshoppers hatch. They withstand a longer period of feeding than late-seeded crops. The grower has a better opportunity to kill the grasshoppers with chemicals.

When small grains are ripening, flying grasshoppers frequently gang up in late-seeded crops that are still green and succulent. Such crops are often severely damaged before the grasshoppers are noticed. Well-advanced crops are much less attractive. Barley, oats, and wheat that have headed can withstand considerable defoliation without serious reduction in yield of grain.

OTHER MEASURES

Insecticides and proper tillage and seeding are the best weapons for fighting grasshoppers, but now and then you may be able to combat them in other ways.

Regrassing Field Margins

Studies in the northern Great Plains have shown that weedy margins, including roadsides and fence rows, contain more eggs of the migratory grasshopper than any other habitat. Replacing broad-leaved weeds with perennial grasses greatly reduces the number of grasshoppers in these locations.

Native or prairie grass attracts few migratory grasshoppers, but it requires such a long time to become established that its use is not feasible in a regrassing program. Crested wheatgrass can be used for this purpose. It is easily and quickly established and is even less attractive for egg laying than native grasses.

Elimination of weeds and prevention of soil erosion are additional benefits of grassed field margins. Increased farm returns derived from the grass grown along otherwise unproductive field margins may also be of some importance.

Immune Crops

Some of the sorghums, such as sorgo and kafir, after reaching a height of 8 to 10 inches are practically immune to grasshopper attack. They can be planted rather late in the season to provide valuable feed for livestock.

Irrigation

When alfalfa and other legumes are irrigated, large numbers of grasshoppers are sometimes driven to ditchbanks and other dry places, where they can be killed with spray or dust at slight expense. Flooding hay meadows where eggs of the clear-winged grasshopper have recently hatched will destroy many of the young hoppers.

COMMUNITY ACTION

Where grasshoppers originate on a particular farm and menace only the crops on that farm, individual action is sufficient. However, if they are present in such numbers that they are likely to move from one farm to another, community action is needed. When severe outbreaks extend over large areas, county, State, and Federal cooperation is essential to successful control. This is particularly true in range areas, where some of the land is privately owned, some is owned by State governments, and some is owned by the Federal Government. Failure of any of the owners to cooperate makes control more difficult for the others.

The Agricultural Research Service, United States Department of Agriculture, cooperates in a number of ways in controlling grasshoppers. Research is conducted to improve grasshopper control and lower its cost. Surveys are made in cooperation with State agencies to find out where control will be needed. Control and research personnel meet with State leaders in grasshopper control at annual conferences to discuss survey reports, research findings, and plans for control operations. Field supervisors are employed to assist State leaders in their control programs and to direct grasshopper control on federally owned land.

Fight Your Insect Enemies

U. S. GOVERNMENT PRINTING OFFICE: 1954

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 20 cents